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Analysing advanced concepts for operations room layouts

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ANALYSING ADVANCED CONCEPTS FOR OPERATIONS ROOM LAYOUTS

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Three preliminary configurations for the Integrated Command Environment (ICE) of a future USN platform were evaluated in a proof-of-concept study, using the LOCATE layout analysis tool developed in Canada. LOCATE, which develops a cost function reflecting the quality of all human-human and human-machine communications within a workspace, showed little difference between the efficacy of the preliminary designs selected for comparison. It was concluded that this was due in part to the limitations of the study, which included the assumption of a similar size for each layout and the adoption of a common size for each workstation. Based on these results, the USN offered an opportunity to conduct a LOCATE analysis using more appropriate assumptions. A standard crew was assumed, and subject matter experts agreed on the communications patterns for the analysis. Eight layouts were evaluated with the concepts of *co-ordination* and *command* factored into the analysis. Clear differences between the layouts emerged, with the most promising design being further refined by the US.

INTRODUCTION

The United States Navy (USN) DD-21 project involves the development of requirements for new expeditionary force ships for the 21st century. Part of the DD-21 project involves the development of an Integrated Command Environment (ICE) for these vessels. Stated objectives for ICE design include designing for: (1) effective mission performance and ship control; (2) effective/appropriate application of technologies; (3) operational utility; (4) assistance in manning reduction goal; (5) reconfigurability; and (6) a level of comfort supporting potentially long watchstanding periods.

These objectives reflect a desire for optimized manning and improved human interface technologies. At the heart of effective command is a layout that allows crew members to be physically organized in ways that will optimize their communication and interaction.

A workshop for the Integrated Command Environment Collaboration on Operation and Layout Design (ICE COLD) was held at the Decision Support Center (DSC) and the Control Systems Advanced Concepts and Technologies (CSACT) Laboratory, Naval Surface Warfare Center, Dahlgren Division (NSWCDD) on 19-23 April 1999. The purpose of this workshop was to formulate a Concept of Operations (CONOPS) for notional ICE concepts. Attendance included members of both DD 21 acquisition teams (Blue and Gold), system engineers, human factors engineers, and warfighters.

Under the auspices of the Technical Cooperation Program, Technical Panel 9 of the Human Resources Group (TTCP HUM TP-9), the Canadian Department of National Defence (DND) agreed to apply a developmental software tool called LOCATE (Hendy, 1984; Hendy, 1989) to the assessment of command room layouts that were expected to emerge from this meeting.

LOCATE is a tool used to quantitatively assess the communication and interaction efficiency of multi operator (humans and machines) 2-D layouts in the four communication domains: visual, auditory, tactile (reach) and distance (or movement). Traditional methods of addressing this problem have focused only on the distance (or movement) domain and, thus, are limited in the information

they can provide about many real-world layouts. LOCATE's analysis allows the injection of a much stronger representation of human capabilities and limitations than traditional link analysis. LOCATE is sensitive to both distance and angular relationships. Through the incorporation of link strength functions (LSFs) LOCATE can also model the effects of human capabilities and limitations in each communication domain of interest (Hendy, 1989). LSFs represent the *strength* or *goodness* of a communication link in either the distance or angular dimension of each communication domain.

The work reported here extends earlier proof-of-concept studies that demonstrated the usefulness of the LOCATE tool in analyzing three early concepts for ICE, and in assessing four prototype bridge designs for the Canadian DD-280 destroyer project (Hendy, Berger, and Wong, 1989). As a result of that work, and a presentation to USN and associated personnel at DCIEM in March 1999, an invitation was issued to Canada to contribute to the ICE COLD workshop. This ICE analysis was to address issues related to assumptions made about the size of layouts and workstations for the earlier proof-of-concept study, that might have limited the sensitivity of the earlier results.

ELEMENTAL WORKSTATIONS

Eight operators and four displays were modeled in LOCATE. They are

Operators

1. Commanding Officer (CO)
2. Commander's Deputy (CDO)
3. Air Warfare (AW)
4. Land Warfare (LW)
5. Surface/Subsurface Warfare (SW)
6. Ship's Systems Management 1 (SSM1)
7. Ship's Systems Management 2 (SSM2)
8. Special Evolutions (SE)

Displays

9. Common Tactical Picture (CTP)
10. Special Tactical Picture (STP)
11. External Picture (EP)
12. Ship's Status (SS)

DOMAINS OF COMMUNICATION AND INTERACTION

Human-human and human-machine interactions were represented in four domains of communication: (1) Vision, (2) Audition, (3) Reach, and (4) Distance. Modeling within the domains of audition and reach was straightforward. However, based on discussions during the first days of the workshop, an attempt was made to incorporate the effects of **coordination** and **command** into the LOCATE analysis. Coordination was introduced through the visual domain for human-human interactions — command through the distance domain. LSFs and priority matrices were created and reviewed by the DND team plus two of the ICE evaluation team members with operational experience.

LINK STRENGTH FUNCTIONS

LOCATE models bi-directional communication allowing each element in a workspace to be both a source and receiver of information. Link strengths are attenuated by the presence of physical obstructions, then weighted by their relative priorities before, being summed over all workstations and communication domains (this time weighted by relative domain importance). The sum of all attenuated link strengths represents the overall quality of communication in the workspace. To be compatible with many mathematical optimization packages, this number is subtracted from 1 (best possible performance) to generate a *cost function* value.

Visual Domain. LSFs in the visual domain were used to model both the potential for co-ordination in human-human interactions, and the strength of information exchange for human-display interactions. Coordination was assumed to be facilitated by visual contact with the team. Obviously coordination will also depend on communication links such as audition, however voice links are dealt with separately in the analysis of the auditory domain. Because the visual domain was being used to model two effects, an *ability to be coordinated* property was attributed to the source link of all human operators. It was assumed that the strength of this ability would degrade with distance but would not be sensitive to the orientation of the person being coordinated (unlike the *potential to be commanded* — see the distance domain LSFs). Lacking quantitative data, a linear degradation of the *ability to be coordinated* property with distance was assumed.

Auditory Domain. The assumption was made that communication would be aided by an amplified voice communication system, but that important cues were available from facial expressions and *body language*. Therefore, no distance penalty is applied to voice communication due to a loss of acoustic signal strength. However, face-to-face communication is favored in the analysis by requiring a source of auditory information to be within the receiver's first and second quadrants in azimuth. A Butterworth function (Storer, 1957, p.287) with sharp shoulders (10^{th} power) was chosen to span the central 180°of the receiver's visual field No auditory display characteristics were modeled although it is recognized that the four dis-

plays included in these layouts may have an auditory component. As it had already been assumed that voice interactions would be aided by a personal amplifying system, audio from various display devices could be added to this system.

Tactile Domain. LSFs in this domain are straightforward and are derived from standard shirt sleeved reach capabilities of human operators (e.g., see Van Cott and Kinkade, 1972, Table 11-76). No attempt was made to be exact, but 2.5 feet (30in) is a reasonable figure for the reach of a 5th percentile shirt-sleeved male operator, 20 inches above the seat reference point, over the first and second quadrants in azimuth. Reaches behind the operator were heavily penalized (by the use of a Butterworth function with sharp cut-offs at ±90°). A coefficient of variation of 10% was assumed. Although these figures are ostensibly for male operators, a SD of 3in, and the ability to move the trunk to extend reach, allows for considerable variability and the accommodation of female operators.

Distance Domain. Movement within the workspace was not included in these analyses. Rather the distance domain was used to capture the *potential to be commanded.* A source of *potential to be commanded* was attributed to all human elements in the ICE space. This potential was assumed to depend on distance from the commander and on the facial aspect seen. A Complementary Error Function (Burington and May, 1970, p43, 112) was chosen to represent a diminishing *potential to be commanded* as distance increased, having a mean distance of 12 feet (corresponding to the 50% point) and a standard deviation of 3 feet. *Potential to be commanded* was also assumed to depend on facial aspect. This potential was considered to erode quickly as team members were viewed from their 3rd and 4th quadrants (i.e., the back of their heads). A Butterworth function with sharp cut-offs at ±90° was used.

For the commander, high command potential exists in the 1st and 2nd quadrants but degrades rapidly in the 3rd and 4th. Again a Butterworth function with sharp cut-offs at ±90° was used. No receiving penalty is incurred with distance as this is already contained in the source properties of all human elements.

LINK PRIORITIES AND DOMAIN WEIGHTS

Two subject matter experts with operational experience participated in assigning priority weights to each of the links (source and receiver) in the domains of interest. Priorities were assigned for the domains of audition [A], distance [D], tactile [T] and visual [V].

For ease of implementation, priorities were assigned on a 10-point scale (0 to 10) and later transformed to the range 0 to 1 for entry into LOCATE. Note that priorities do not have to be symmetrical, although they can be if this is an appropriate description of the flow of information. For example, while coordination may be a symmetrical concept, command is not. Generally, audition and reach between humans is likely to be more symmetrical than not.

Only second order links (element to element) were considered. No first order links (due to absolute position within the workspace) were analyzed. All priorities exerted an attractive (positive) force during optimization. No negative priorities were included, although LOCATE will allow repulsive forces to be modeled (e.g., to remove workstations from noise sources or to model the need for privacy). Cost functions were obtained with all domains (visual/co-ordination, auditory, tactile, and distance/command) active. Domains were weighted equally (all 2nd order domain weights = 1).

TABLE 1 Cost function values for eight notional designs for the ICE.

	Attribute	Cost
A	Outward facing, central executive with displays arranged around the outside.	0.158
B	Inward facing, boardroom layout with executive at one end and displays at the other	0.064
C	Amphitheater with displays on one wall.	0.093
D	Inward facing cellular arrangement with distributed overhead displays.	0.050
E	Inward facing, roundtable with wall displays.	0.035
F	Inward facing with centralized displays.	0.032
G	Inward facing with displays ceiling hung or placed around the outer walls.	0.048
H	Two huddles (warfare and ship's systems) with a central executive.	0.060

THE ICE LAYOUTS

In addition to four configurations analyzed by the LOCATE team while at Dahlgren, a fifth configuration (E) was added after the team returned to Toronto. All of the configurations were developed over the course of the workshop and LOCATE analyses were run for each. Brief descriptions of these configurations (labeled A-E), and the

LOCATE results, appear in Table 1. The cost function results, which are LOCATE measures of communication efficiency, appear in Column 3 of that Table; the lower the cost function value, the more efficient the configuration.

RESULTS

As can easily be seen from Table 1, the most efficient of the original configurations is E, a layout with wall displays, in which the players are facing inward toward each other. In fact, all inwardly facing layouts are more efficient by half, at least, than the one outwardly facing layout (A). A more detailed description of all configurations can be found in (Edwards, 1999).

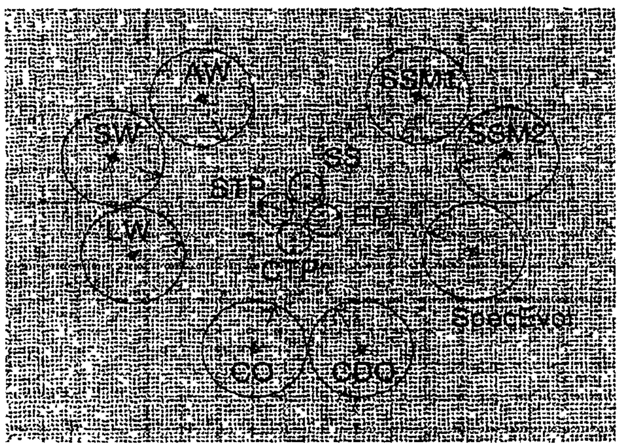

Figure 1. *The best of the layouts from the DD-21 ICE evaluations (Configuration F) in terms of the LOCATE analysis.*

Recent work on LOCATE has reintroduced limited optimization capabilities, which proved to be of value in extending the analysis of the ICE designs. LOCATE's optimizer produced three additional designs (F-H in Table 1) with a common theme: all configurations tended to an inward facing arrangement with clustered executive, warfare and ship's systems cells, and common use displays in a central location. Configuration F (see Figure 1) is the most efficient of the eight analysed. Configuration G is more efficient than four of the five original configurations; the exception was Configuration E, the inward facing roundtable. Configuration H is the least efficient of the new optimized configurations but strikes a balance between inward and outward facing arrangements. In this configuration, the executive is placed in between the other two cells and can rotate to bring them into view as needed. In spite of its showing relative to the other optimized configurations, it is substantially improved over the outward-facing configuration of the initial set.

Unlike the earlier proof-of-concept study of the DD-21 configurations, substantial differences were found between the arrangements of Table 1. In December 1999, a FY00 ICE concept based on Configuration E/F was added to the earlier FY99 layouts for further investigation in the ICE simulation laboratory setting at NWSCDD.

CONCLUSIONS

The history of use to date clearly shows that LOCATE can be used to assist in the comparative assessment of workspace layouts as complex as ship's bridges and command centers.

It takes information such as communication and movement patterns, link and domain priorities, and performs an overall assessment of the how well the layout of humans and machines supports the efficiency of communication. Through LOCATE's sensitivity to both distance and angular link relationships, and the use of link strength functions, a range of human visual, auditory, and tactile capabilities and limitations can be represented. In the ICE studies reported here, issues as complex as team coordination and command were partially addressed through to tools available in LOCATE.

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